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Experimental study of corrugated metal-composite tubes under axial loading

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Abstract

In this study, crushing behaviour of corrugated metal-composite tube was examined experimentally under axial loading condition. Six types of specimens, classified into two groups of metal and metal-composite, were tested under quasi static axial loading. The failure mechanism and failure history of the specimens were presented and discussed. The experimental result showed that corrugated metal composite tubes demonstrate perfect energy absorption characteristics in terms of uniformity of load-displacement diagram, reduction of initial peak load and controlling failure mechanism. Moreover, it was also found that adding filament wound layer of composite on the surface of metallic corrugated tube compensated weakness of corrugated metal tubes, which is low energy absorption capacity. Metal-composite corrugated showed high energy absorption capacity as well as preferable crushing characteristic under the axial loading.

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Keywords: Corrugated tube, Energy absorption, experimental analysis, Quasi-static experiments, axial compression, Peak load

1. Introduction

In the last two decades, many researchers dedicate their research to study crush behaviour of thin-walled metal or composite tubes. Considering excellent absorption efficiency, lightweight and low cost of manufacturing, thin walled tubes are the most popular (or the most widely used) energy absorbing devices.

Large amount of studies utilizing theoretical, numerical and experimental methods has been conducted to better explore thin walled tubes and their capacity to absorb energy. Various cross section such as square, circular,

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hexagonal, top hat, etc. [1–4] has been investigated. Among many shapes, circular metal tubes are one of the most popular shapes of thin walled energy dissipating devices that absorb kinetic energy of impact by collapsing in concertina and diamond folding modes. Alexander's work [5] was one of first analytical studies conducted on straight tubes.

The most effective method of energy dissipation for metal thin walled structures under axial impact is plastic deformation. Energy absorption performance and collapse mechanism of different materials such as metal and composite. Thanks to light weight and high strength characteristics, composite structures became one of best alternative for metallic tubes [6–10]. Researchers tried different configuration for energy dissipation devices to improve their controllability, energy absorption capacity and performance. Configuration such as bi-tubular tubes is an effective way to increase energy absorption capacity by interaction[11,12]. Using honeycombs [13–16] and foams[17,18]are also other approaches to increase interaction and improve energy absorption characteristics of thin walled structures.

Experimental research and theoretical analysis conducted by Yu [6,7] presented experimental and analytical investigations on deformation of circular tubes. Results showed that shifting form an axisymmetric or mixed mode to a non-axisymmetric mode could occur by using special type of buckling initiator for large progressive deformation of axially crushed circular tubes.

Experimental investigation for corrugated tube has been conducted by Singac [19]. Results showed that corrugated tube has better performance in terms of force fluctuation. Moreover, corrugated tube showed highly controllable characteristic during axial crushing. In order to control the collapse of thin walled tubes, many researchers have suggested introduction of grooves on the surface of traditional metal tubes[20,21]. Haosseinipor et al [22] have performed experimental study for thin walled steel tubes with circumferential grooves under quasi-static compression. The results indicated that by grooving the tube wall they deform more stably.

Niknejad et al. [23] have conducted analytical study in order to predict mean folding force and total absorbed energy per unit length of tube, and specific absorbed energy per unit mass of polyurethane foam-filled grooved tubes under axial compression. Adding stiffener on the surface of tubes is another method of controlling deformation mode which has been studied by Salehghaffari et al. [24] . Thin-walled tubes which were externally stiffened by multiple rings were subjected to quasi static compression and results showed that this type of tube has efficient energy absorption performance. Effect of tapering and introducing axisymmetric indentation has been studied by Acer et al. [25]. Chen et al[26] have numerically simulated corrugated tubes and showed that the deformation mode can be classified into axisymmetric and asymmetric modes for corrugated tubes under axial load.

In order to minimize damage to vehicle energy absorber, device should have capacity to absorb large amount of energy and meanwhile be lightweight to reduce fuel consumption[27–30]. In the case of misaligned crushing energy absorber should have reliable performance [31]. Many researchers tried numerical optimization in order to find optimized design for crash absorbing components [25,32,33].

Controlling deformation mode and wavelength of progressive buckling is one way to have denser collapse formation [34,35]. Composite materials also have high capacity of energy absorption and many researchers have conducted studies to understand behaviour of this type of tubes as energy dissipation devices[36–40]. Elgalai et al. [41] have studied crushing of composite corrugated tubes under quasi static loading. Experimental results showed that changing corrugation angel and fiber type enhance the energy absorption performance of composite tube.

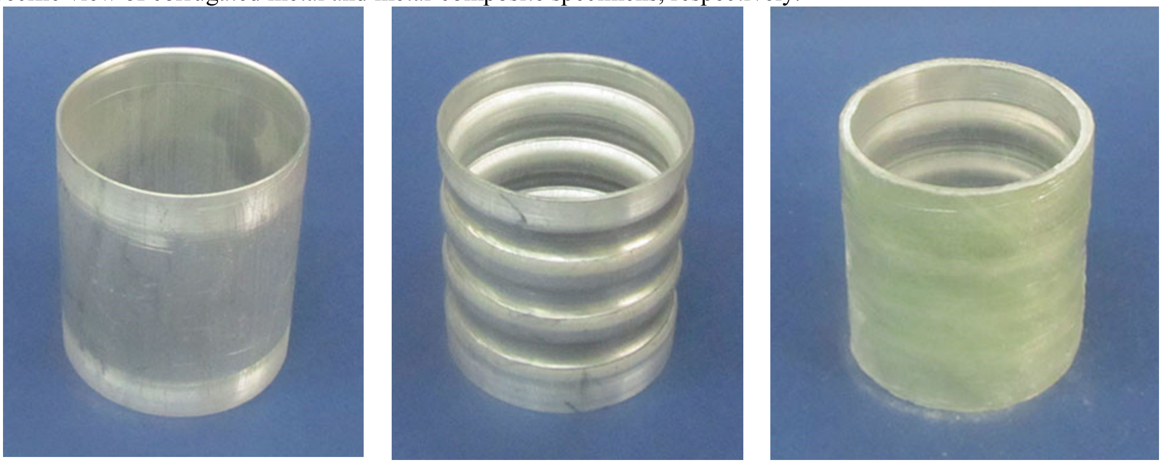
Previous investigation for corrugated tubes showed that they have better energy absorption performance in comparison to traditional straight tubes. However, these studies focused only on the axial compression experiments and finite element numerical simulations under quasi-static loading conditions. Although corrugated tube exhibit very good energy absorption characteristics, there are few papers published on the experimental investigation of corrugated metal tubes under axial impact loading conditions. For corrugated metal-composite tube there is no available report in the literature. In the present study, the energy absorption behaviour of corrugated metal and metal-composite tubes under axial loading condition was dealt. Three different types of specimens were fabricated and tested experimentally. Effect of adding composite and corrugation geometry were determined to understand the response and energy absorption properties of corrugated metal-composite tubes.

2. Experiments: description and result

In this investigation, we have used experimental methods to examine energy absorption under axial quasi-static loading. Although, these devices are generally used in higher velocities, usually quasi-static loading is analysed first, because similar predominant geometrical effects occur under dynamic loading.

2.1. Testing specimens

In order to have same material properties for all specimens, they were cut from single aluminium tube. The overall height of all the specimens was 70mm. Lath machine was used for precise trimming of specimens. To obtain perfect and progressive buckling, the tubes cross-sectional thickness was chosen to be t=1.5 mm. Figure1 illustrates specific view of corrugated metal and metal-composite specimens, respectively.



S SWCD CWCD

Figure1: Close view of corrugated meta and metal -composite specimens

Details of specimen's geometry for lateral compression are shown in Table 1.

Table 1 - details of tested specimens

	Number of corrugation	Corrugation length (mm)	Corrugation depth (mm)	Description
S	no corrugation	---	---	**S**imple (metal without composite)
SWCD	3	18	3.5	**S**imple **w**ith **c**orrugation **d**eep
CWCD	3	18	3.5	Metal- **C**omposite **w**ith **c**orrugation **d**eep

2.2. Material property

All samples in this research were made of aluminium alloy. The material properties were obtained by carrying out quasi-static tensile tests on extruded tube. Cut strips were parallel to the tube axis. Aluminium strips were cut from three different parts of tube, including its two ends and one from centrepiece. Then tension test was carried out on those three different pieces. Engineering Stress-strain curves and shape of one of those strips is demonstrated in figure 2.

2.3. Preparation of Test Specimens

Aluminium alloy tubes were used instead of other materials like mild steel because this alloy has better forming characteristics. In addition, aluminium is very affordable and easily accessible. Corrugations method was based on stamping process. Harden steel was cast-off to make the dies for the process and consists of different parts opposed to each other.

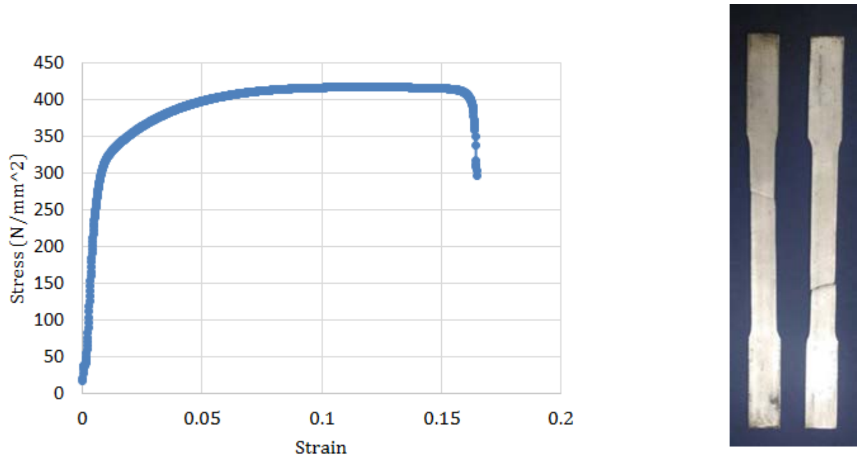


Figure 2: Representative engineering stress-strain curves of tested tubes.

To make corrugation, a special machinery has also been invented. Then the dye was fitted in the machinery and placed in adjacent axes with opposed directions by gear transmission system and the tubes were tightened between two dies whilst rotation, gradually the two dies move closer to each other. Additionally, variation of corrugation depth is possible by choosing different axis distance for two opposite dies. Figure 3, demonstrates the corrugated tube and the dies assembly.

Figure 3: Stamping technique for fabrication of corrugations.

Figure 4: alignment for filament winding process

After producing corrugation, filament wingding process was applied on tubes. All tubes including corrugated and non-corrugated tubes were fixed on single plastic tubes and filament winding process was performed for all of them simultaneously.

In this way, filament winding condition was constant for all specimens. Three layers of composite were added to surface of all specimens. First layer was chosen +-45 degree and the two other layers was 90 degrees. Figure 4 shows alignment for filament winding process.

In filament winding process, glass fiber with a density 2400 gr/m^3 and an epoxy resin (mixture ratio with hardener was 100 to 50, were employed Filament wound specimens were exposed to heater in order to make them dry. Then, the specimens were put in oven with a temperature of 80 C for 3 hours to be post-cured. Cutting and aligning of metal-composite tube was then done precisely.

2.4. Testing Method

All the experiments were performed by a universal testing machine in Qatar University. The experiment setup is showed in Figure 5. The tubes were tested in quasi-static loading. The load-displacement curve was obtained for each case.

A specimen experimented on quasi-static axial loading in instruction universal testing machine with the full-scale load of 200kN was utilized. This machine is calibrated every year. during the compression tests, samples were put between two equivalent steel plates of the machine, without any further boundaries. Before testing, the load plates were set parallel to each other. Axes of rigid plates, tubes and testing machine were also aligned carefully. Figure 5 shows the schematic of tube and rigid plates of testing machine. To stimulate quasi-static condition and make sure that no dynamic effect exists, all tubes were tested at a displacement rate of 5 mm/min. Compression test were stopped when sharp increase observed in load-displacement diagram which indicates complete crushing of the tubes. Built in automatic data acquisition system was used to record the load and displacements.

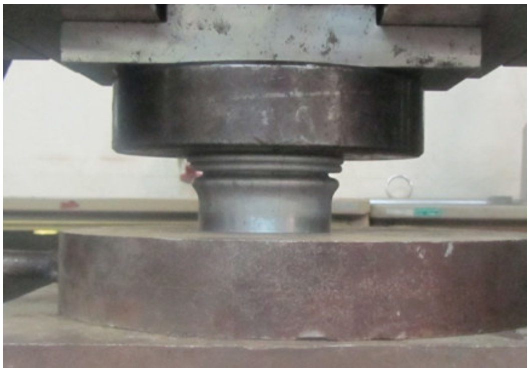


Figure 5: metal tube compression

2.5. Experimental results

Different energy absorption devices were designed for various purposes. The designer requires to know the various characteristics of energy absorbers in detail. Hence, various parameters were defined to evaluate diverse absorbers with ease. These parameters would be discussed further below.

Mean crushing load (N): The average crushing load response of absorber in complete deformation is called the Mean load.

Total absorbed energy (J): During the crushing process, we can acquire absorbed energy by using the calculations of area under the load-displacement curves. Numerical integration was used to calculate total absorbed energy in this study. For instance, figure 6 illustrates load-displacement curve for different specimens. The total absorbed energy is the area under given curves.

Specific absorbed energy(J/g): The result of dividing total absorbed energy by the weight of energy absorption device.

In this section, experimental result is presented. Table 2, gives detail results from experiments.

Table 2- experimental detailed result for all specimens

	S	SWCD	CWCD
mean load (N)	2.08E+04	1.22E+04	3.45E+04
absorbed energy (J)	1.04E+03	6.10E+02	1.73E+03
specific absorbed energy (J/g)	1.35E+01	7.92E+00	1.21E+01

In the load–displacement diagram, there are two stages; the first stage which is considerably a high load and is called initial peak (for tubes without corrugation).

This stage is followed by steady fluctuations which are related to formation of hinges (as second stage). This stage keeps the deformation process until the tube is crushed fully. The last stage implies the end of crushing, due to sharp increase in the load response. Experimental results for three specimens are shown in figure 6

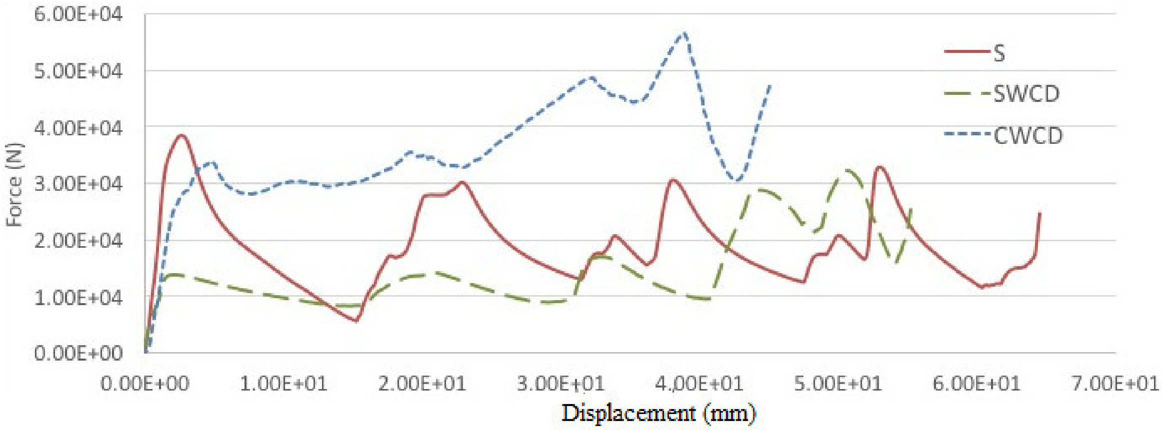


Figure 6- experimental result for all specimens

3. Discussion

3.1. effect of corrugation on metal tubes

As it was discussed in pervious study [42,43] corrugation has significance effect on first pick load and load displacement diagram fluctuation. As it can be seen in figure 6, in which the straight metal tube (S) and corrugated tube (SWCD) were compared, it can be concluded that corrugation decreases the first initial peak load as well as fluctuation of crushing load. However, a negative effect of corrugation is decreasing total absorbed energy which is due to plastic work. It may be claimed that this plastic work was absorbed by tubes during corrugation process. Also, mean load decreased from 2.08E+04 (N)to 1.22E+04 (N) (a 41.4 % reduction). In order to compensate this negative effect, (as is discussed in the next section) composite layers were added to metal tube.

3.2. effect of adding composite layers on corrugated tubes

Adding composite layers to corrugated or straight tube increases the energy absorption capacity of metal tubes. As it can be inferred from figure 6, adding composite layers to corrugated tube (specimen SWCD and CWCD) increases the mean load by 280 %, and by considering weight of the tubes, the specific absorbed energy increases by 53 %. Simultaneously, composite layers lead to a reduction in load-displacement diagram fluctuation more than corrugated metal tube. However, adding of composite layers relatively increases the initial peak load which is not desirable. This can be interpreted that composite makes tube more stable for initial elastic deformation which is responsible for initial peak load.

By comparing composite-metal corrugated and straight metal tubes, it can be inferred that specific absorbed energy for both type are very close (1.35E+01 (J/g) for straight metal tube and 1.21E+01 (J/g) for metal-composite tube). Moreover, composite-metal tubes have very desirable energy absorption characteristic which is no initial peak load, smooth load-displacement diagram, and stable crushing mode. In other words, this type of tubes, thanks to the existence of composite layers, do not have disadvantages of corrugated metal tubes which is low energy absorption capacity, meanwhile they have all desirable characteristic for energy absorber.

4. Conclusion

When the corrugation patterns are introduced into traditional metal circular tube, the corrugated tube undergoes plastic deformation and folding according to the predesigned patterns. Following conclusion can be drowning:

- The initial peak force and fluctuation of load-displacement diagram for corrugated metallic tubes is clearly less than those for circular straight tubes.
- Corrugation makes deformation mode more stable and controllable for both metal and metal-composite tubes.
- Load-displacement diagram for corrugated tube has less fluctuation in comparison to straight tube. This desirable characteristic of corrugated tube can be improving by adding composite layers to their surface. Corrugated metal composite tubes have better absorption characteristics in terms of fluctuation of response load.
- Adding composite to corrugated metal tube compensate their weakness which is low energy absorption capacity. Specific absorbed energy of composite corrugated tube is 53 % higher in comparison to corrugated tube.

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References

[1] R.D. Hussein, D. Ruan, J.W. Yoon, An Experimental Study of Square Aluminium Tubes with Honeycomb Core Subjected to Quasi-Static Compressive Loads, Key Eng. Mater. 626 (2014) 91–96. doi:10.4028/www.scientific.net/KEM.626.91.
[2] J. Rouzegar, H. Assaee, A. Niknejad, S.A. Elahi, Geometrical discontinuities effects on lateral crushing and energy absorption of tubular structures, Mater. Des. 65 (2015) 343–359. doi:10.1016/j.matdes.2014.09.041.
[3] M.A. Guler, M.E. Cerit, B. Bayram, B. Gerçeker, E. Karakaya, The effect of geometrical parameters on the energy absorption characteristics of thin-walled structures under axial impact loading, Int. J. Crashworthiness. 15 (2010) 377–390. doi:10.1080/13588260903488750.
[4] S. Mohsenizadeh, R. Alipour, M. Shokri Rad, A. Farokhi Nejad, Z. Ahmad, Crashworthiness assessment of auxetic foam-filled tube under quasi-static axial loading, Mater. Des. 88 (2015) 258–268. doi:10.1016/j.matdes.2015.08.152.
[5] J.M. Alexander, An approximate analysis of the collapse of thin cylindrical shells under axial loading, 13 (1960) 10–15. doi:10.1093/qjmam/13.1.10.
[6] T.A. Sebaey, E. Mahdi, Crashworthiness of pre-impacted glass/epoxy composite tubes, Int. J. Impact Eng. (2014). doi:10.1016/j.ijimpeng.2015.11.007.
[7] E. Mahdi, T.A. Sebaey, Crushing behavior of hybrid hexagonal/octagonal cellular composite system: Aramid/carbon hybrid composite, Mater. Des. 63 (2014) 6–13. doi:10.1016/j.matdes.2014.06.001.
[8] E. Mahdi, T.A. Sebaey, Crushing behavior of hybrid hexagonal/octagonal cellular composite system: Aramid/carbon hybrid composite, Mater. Des. 63 (2014) 6–13. doi:10.1016/j.matdes.2014.06.001.
[9] M. Moeinifard, G. Liaghat, G. Rahimi, A. Talezadehlari, H. Hadavinia, Experimental investigation on the energy absorption and contact force of unstiffened and grid-stiffened composite cylindrical shells under lateral compression, Compos. Struct. 152 (2016) 626–636. doi:10.1016/j.compstruct.2016.05.067.
[10] W. Tan, B.G. Falzon, M. Price, H. Liu, The role of material characterisation in the crush modelling of thermoplastic composite structures, Compos. Struct. 153 (2016) 914–927. doi:10.1016/j.compstruct.2016.07.011.
[11] M. Haghi Kashani, H. Shahsavari Alavijeh, H. Akbarshahi, M. Shakeri, Bitubular square tubes with different arrangements under quasi-static axial compression loading, Mater. Des. 51 (2013) 1095–1103. doi:10.1016/j.matdes.2013.04.084.
[12] A. Alavi Nia, S. Chahardoli, Optimizing the layout of nested three-tube structures in quasi-static axial collapse, Thin-Walled Struct. 107 (2016) 169–181. doi:10.1016/j.tws.2016.06.010.
[13] R.D. Hussein, D. Ruan, G. Lu, I. Sbarski, Axial crushing behaviour of honeycomb-filled square carbon fibre reinforced plastic (CFRP) tubes, Compos. Struct. 140 (2016) 166–179. doi:10.1016/j.compstruct.2015.12.064.
[14] S.A. Galehdari, M. Kadkhodayan, S. Hadidi-Moud, Low velocity impact and quasi-static in-plane loading on a graded honeycomb structure; experimental, analytical and numerical study, Aerosp. Sci. Technol. 47 (2015) 425–433. doi:10.1016/j.ast.2015.10.010.
[15] S.A. Galehdari, M. Kadkhodayan, S. Hadidi-Moud, Analytical, experimental and numerical study of a graded honeycomb structure under in-plane impact load with low velocity, Int. J. Crashworthiness. 20 (2015) 387–400. doi:10.1080/13588265.2015.1018739.
[16] S.A. Galehdari, H. Khodarahmi, Design and analysis of a graded honeycomb shock absorber for a helicopter seat during a crash condition, Int. J. Crashworthiness. 8265 (2016) 1–11. doi:10.1080/13588265.2016.1165440.
[17] D. Meric, H. Gedikli, Thin-Walled Structures Energy absorption behavior of tailor-welded tapered tubes under axial impact loading using coupled FEM / SPH method, Thin Walled Struct. 104 (2016) 17–33. doi:10.1016/j.tws.2016.03.002.
[18] S. Mohsenizadeh, R. Alipour, Z. Ahmad, A. Alias, Influence of auxetic foam in quasi-static axial crushing, Int. J. Mater. Res. 32 (2016)

146.111418. doi:10.3139/146.111418.
[19] A.A. Singace, H. El-Sobky, Behaviour of axially crushed corrugated tubes, Int. J. Mech. Sci. 39 (1997) 249–268. doi:10.1016/S0020-7403(96)00022-7.
[20] M.J. Rezvani, A. Jahan, Effect of initiator, design, and material on crashworthiness performance of thin-walled cylindrical tubes: A primary multi-criteria analysis in lightweight design, Thin-Walled Struct. 96 (2015) 169–182. doi:10.1016/j.tws.2015.07.026.
[21] M.J. Rezvani, M.D. Nouri, Axial crumpling of aluminum frusta tubes with induced axisymmetric folding patterns, Arab. J. Sci. Eng. 39 (2014) 2179–2190. doi:10.1007/s13369-013-0734-7.
[22] S.. Hosseinipour, G.. Daneshi, Energy absorbtion and mean crushing load of thin-walled grooved tubes under axial compression, Thin-Walled Struct. 41 (2003) 31–46. doi:10.1016/S0263-8231(02)00099-X.
[23] A. Niknejad, Y. Abdolzadeh, J. Rouzegar, M. Abbasi, Experimental study on the energy absorption capability of circular corrugated tubes under lateral loading and axial loading, Proc. Inst. Mech. Eng. Part D J. Automob. Eng. 229 (2015) 1739–1761. doi:10.1177/0954407014568130.
[24] S. Salehghaffari, M. Rais-Rohani, A. Najafi, Analysis and optimization of externally stiffened crush tubes, Thin-Walled Struct. 49 (2011) 397–408. doi:10.1016/j.tws.2010.11.010.
[25] E. Acar, M.A. Guler, B. Gereker, M.E. Cerit, B. Bayram, Multi-objective crashworthiness optimization of tapered thin-walled tubes with axisymmetric indentations, Thin-Walled Struct. 49 (2011) 94–105. doi:10.1016/j.tws.2010.08.010.
[26] D.H. Chen, S. Ozaki, Circumferential strain concentration in axial crushing of cylindrical and square tubes with corrugated surfaces, Thin-Walled Struct. 47 (2009) 547–554. doi:10.1016/j.tws.2008.10.003.
[27] M. Pahlavani, J. Marzbanrad, Crashworthiness study of a full vehicle-lumped model using parameters optimisation, Int. J. Crashworthiness. 20 (2015) 573–591. doi:10.1080/13588265.2015.1068910.
[28] M. Kiani, I. Gandikota, M. Rais-Rohani, K. Motoyama, Design of lightweight magnesium car body structure under crash and vibration constraints, J. Magnes. Alloy. 2 (2014) 99–108. doi:10.1016/j.jma.2014.05.005.
[29] M. Kiani, A.R. Yildiz, A Comparative Study of Non-traditional Methods for Vehicle Crashworthiness and NVH Optimization, Arch. Comput. Methods Eng. (2015) 1–12. doi:10.1007/s11831-015-9155-y.
[30] A. Niknejad, M. Moeinifard, Theoretical and experimental studies of the external inversion process in the circular metal tubes, Mater. Des. 40 (2012) 324–330. doi:10.1016/j.matdes.2012.04.005.
[31] M.B. Azimi, M. Asgari, A new bi-tubular conical-circular structure for improving crushing behavior under axial and oblique impacts, Int. J. Mech. Sci. 105 (2016) 253–265. doi:10.1016/j.ijmecsci.2015.11.012.
[32] N. Tanlak, F.O. Sonmez, Optimal shape design of thin-walled tubes under high-velocity axial impact loads, Thin-Walled Struct. 84 (2014) 302–312. doi:10.1016/j.tws.2014.07.003.
[33] N. Tanlak, F.O. Sonmez, M. Senaltun, Shape optimization of bumper beams under high-velocity impact loads, Eng. Struct. 95 (2015) 49–60. doi:10.1016/j.engstruct.2015.03.046.
[34] D. Agrawal, S. Rawat, A.K. Upadhyay, Crashworthiness of Circular Tubes with Structurally Graded Corrugations, in: SAE Tech. Pap., SAE International, 2016. doi:10.4271/2016-28-0050.
[35] C. Kılıçaslan, Numerical crushing analysis of aluminum foam-filled corrugated single- and double-circular tubes subjected to axial impact loading, Thin-Walled Struct. 96 (2015) 82–94. doi:10.1016/j.tws.2015.08.009.
[36] W. Tan, B.G. Falzon, Modelling the crush behaviour of thermoplastic composites, Compos. Sci. Technol. 134 (2016) 57–71. doi:10.1016/j.compscitech.2016.07.015.
[37] A.E. Ismail, A.L.M. Tobi, AXIAL ENERGY ABSORPTION OF WOVEN KENAF FIBER REINFORCED COMPOSITES, ARPN J. Eng. Appl. Sci. 11 (2016) 8668–8672.
[38] A. Ismail, M. Sahrom, Lateral crushing energy absorption of cylindrical kenaf fiber reinforced composites Lateral Crushing Energy Absorption of Cylindrical Kenaf Fiber Reinforced Composites, Int. J. Appl. Eng. Res. 10 (2016) 19277–19288.
[39] J. Bai, P. Seeleuthner, P. Bompard, Mechanical behaviour of ±55° filament-wound glass-fibre/epoxy-resin tubes: I. Microstructural analyses, mechanical behaviour and damage mechanisms of composite tubes under pure tensile loading, pure internal pressure, and combined loading, Compos. Sci. Technol. 57 (1997) 141–153. doi:10.1016/S0266-3538(96)00124-8.
[40] G.S. Dhaliwal, G.M. Newaz, Modeling Low Velocity Impact Response of Carbon Fiber Reinforced Aluminum Laminates (CARALL), J. Dyn. Behav. Mater. 2 (2016) 181–193. doi:10.1007/s40870-016-0057-3.
[41] A.M. Elgalai, E. Mahdi, A.M.S. Hamouda, B.S. Sahari, Crushing response of composite corrugated tubes to quasi-static axial loading, Compos. Struct. 66 (2004) 665–671. doi:10.1016/j.compstruct.2004.06.002.
[42] A. Eyvazian, M. K. Habibi, A.M. Hamouda, R. Hedayati, Axial crushing behavior and energy absorption efficiency of corrugated tubes, Mater. Des. 54 (2014) 1028–1038. doi:10.1016/j.matdes.2013.09.031.
[43] A. Eyvazian, I. Akbarzadeh, M. Shakeri, Experimental study of corrugated tubes under lateral loading, Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl. 226 (2012) 109–118. doi:10.1177/1464420712437307.